

# **Spatial and Temporal Variability of Grain Size and Small-Scale Morphology**

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## **LONG-TERM GOALS**

The long term goal is to test the hypothesis that heterogeneity of coastal morphology on many scales is correlated with heterogeneity in surface sediments, which influences the morphodynamic feedback. In addition, an amphibious crawler is assessed in the field for operation in the energetic surf zone or other sub-aqueous environments and the integration of instruments on the crawler. The crawler will be used as platform to obtain unique autonomous observations to test scientific hypotheses or obtain observations in hazardous field locations.

## **OBJECTIVES**

The specific objectives of this work are to:

- develop and integrate a suite of sensors for efficiently measuring surf zone morphodynamics and hydrodynamics, in particular surface sediment grain size distribution within the surf zone,
- obtain, modify, and evaluate an amphibious surf zone crawler as a platform for nearshore observations,
- test the sensors in the field and obtain measurements of the temporal and spatial variability of sediments and bedforms
- investigate heterogeneity of morphology in the context of the local sedimentological and hydrodynamic conditions.

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## APPROACH

Historically, it has been assumed by most nearshore models that beaches are uniform in grain size and relative smooth. Recent studies have found that this is not the case. Here we hypothesize that heterogeneity of coastal seafloor morphology on many scales is correlated with heterogeneity in surface sediments, which influence the morphodynamic evolution. To test this hypothesis, detailed measurements of grain size, morphology and the hydrodynamic forcing environment are needed. Unfortunately measuring grain size is traditionally tedious and time consuming. As part of this study we are developing a digital imaging system (DIS) for measuring grain size, from which information about the surface grain size distribution can be obtained quickly and inexpensively. The first goal of this work is to make high spatial- and temporal-resolution surveys of grain size using the DIS.

The second goal is to place a diverse suite of instruments (including the DIS) on an autonomous crawler that will operate within the surf zone. To that end, we have to systematically evaluated a Foster-Miller Inc. Talon amphibious crawler's utility as a functional platform for sub-aqueous operations. On land, we have evaluated the crawler's ability to communicate and navigate. We have been evaluating and developing various communication and navigation set-ups for sub-aqueous operation. Once satisfactory communication and navigation set-ups are determined, oceanographic instrumentation will be integrated on the crawler. Jeff Brown (University of Delaware graduate student) and Jamie MacMahan focused on the communication and navigation operation and set-ups, and associated construction. Edie Gallagher and Jenna Brown assisted with surf zone field evaluations. Rob Wyland and Jim Lambert assisted in crawler modifications. Chuck Bernstein and Mitch Gav provided technical and software assistance, and provided spare parts to complete the drivetrain for crawler evaluation.

## WORK COMPLETED

During this third year of the project significant progress has been made on the development of the digital imaging system (DIS). In May 2005, we participated in a field experiment in Sennen, England with the University of Plymouth, those results have been previously reported. In May 2006, we participated in a field experiment in France with the University of Plymouth and the University of Bordeaux. The results from this experiment were presented at the AGU Fall Meeting in Dec 2006 in San Francisco and are presented below. In April 2007, the DIS was used during the RCEX Experiment (MacMahan-ONR Report) in Monterey, CA. Measurements of sediment grain size variability were made across a rip channel/shoal to compliment the extensive fluid and morphological measurements that were being made. These data are being analyzed at this time.

During the third year of the project significant progress has been made on the development of the amphibious crawler as well. The timeline of events leading up to the present is shown.

### Crawler Historical Timeline-

- 1) Crawler received from Foster-Miller Inc. - March 2006
- 2) Broken crawler drive motor determined March 2006; Discussion with Foster-Miller & Electromechanica, Electromechanica contacted and evaluated, motor solution determined April-July 2006

- 3) Electromechanica agreed to fix motors – July 2006
- 4) Crawler with new motors received January 2007, but missing drive sprockets
- 5) New drive sprockets from Electromechanica arrive February 2007, existing tracks do not fit sprockets
- 6) Chuck Bernstein sends spare sprockets which match existing tracks - May 2007
- 7) Navigation poor continues to hamper progress on land, first surf zone deployment May 2007 after completion of the ONR supported Rip Current Experiment (RCEX)
- 8) To increase sub-aqueous navigation, a retractable-float system design and constructed – June 2007
- 9) Seven different surf zone field tests performed in Monterey Bay, CA – July 2007
- 10) An assessment of crawler's performance was submitted and discussed with program manager – August 2007

In addition, a portable cable reel for tethered sandy beach operation was constructed. A portable cart for crawler and equipment transport was constructed for two-man operation on sandy beaches.

## **RESULTS**

### DIGITAL IMAGING SYSTEM

The prototype DIS consists of a 5 megapixel, digital, Nikon D70 camera (purchased with a grant from Franklin and Marshall's faculty development fund), a macro lens with magnifiers, and an Ikelite underwater housing. The light and focus are fixed so the system is easy to handle and control by a diver, where the diver simply presses the plexiglass lens of the housing against the sand and obtains uniform images. Following Rubin's (2004) technique, auto-correlation is run on a digital image and the correlation curve is compared quantitatively to correlation curves used for calibration to determine the sediment grain size and distribution. The calibration curves are generated by photographing sieved sand from the same beach. A sample natural image from Sennen is shown in Fig 1 (left) and its corresponding autocorrelation curve (asterisks) and the required calibration curves (colored lines) are shown in Fig 1 (right).

To estimate mean grain size, Rubin (2004) interpolated the points on the natural curve between the nearest calibration curves at each pixel offset and the averaged. Estimation of grain size distribution is more difficult and, here, we have tested two techniques. First, the natural curve is fit to the calibration set using non-negative linear least-squares regression to give a distribution (or a fraction of each calibration curve that was represented in the natural curve). The least squares regression was found to be a bit unstable and sometimes to give non-sensical results. Thus, we have been working with Ad Reniers to develop a second calibration technique based on a maximum entropy estimator with the hope of a more stable estimate of grain size distribution.

Estimates of sediment grain size distribution are shown in Fig 2. The thin lines in Fig 2 represent grain size distribution estimates from individual images (approximately 20 photographs were taken of the sample). The thick blue line is the average of all the thin lines and represents the grain size distribution estimated from the DIS for that sample. Also shown in Fig 2 is the grain size distribution of the same sample measured using sieves (solid black line). The camera system produces grain size distribution estimates in close agreement with the sieving technique (when many images are averaged).

The left panel shows distribution estimates using Rubin's (2004) least squares fit (LSQ) and the right hand panel shows distributions of the same sample calculated using the maximum entropy estimator (MEE). The MEE estimator gives more stable and accurate estimates of distribution for each individual photo. For example, in comparing the thin green lines in Fig 2, which are distribution estimates for the natural image in Fig 1 (left panel), the MEE results in a distribution that has a sensible shape (albeit slightly coarser than the average distribution), but the distribution estimate from the least squares fit gives a peak at 1.4 mm, a grain size fraction that is not visible in the image. The least squares estimator frequently gives anomalous peaks at very large and very small grain sizes. In addition, the average distributions are slightly more accurate using the MEE estimator. These results are preliminary and the capabilities of the two techniques are being investigated at this time.

Data were collected at Truc Vert, France in May 2006 and particular attention was paid to correcting errors encountered during the Sennen experiment. Results from surveys of grain size at Truc Vert are shown in Fig 3. The grain size clearly varies with location on the beach and in time as a function of wave energy. Before the storm of May 20, coarser sediments were high on the inter-tidal beach face and finer sediments were lower, near the low tide water line. After the storm, when large waves had a chance to rework the sediments, the coarser material had been moved into deeper water, just below the low tide water line. This is consistent with the typical scenario where sediment is moved offshore when wave energy becomes large. These data, although they cover a relatively small, inter-tidal area, show the power of the DIS to detect subtle variations in grain size that are clearly integral to the morphodynamics of the beach. Analysis of the data collected at Ripex is just beginning.

## AUTONOMOUS CRAWLER

The results of our overall assessment of the autonomous crawler for use in the surf zone are as follows:

Currently the crawler requires a minimum of three people for operation. We want to get the system such that it is a two-person operation

- a. Crawler navigation requires improvement for scientific operation, particularly within the surf zone. It now requires a land-based computer operator and at least one swimmer in the water for assistance.
- b. Owing to crawler size, it is unexpectedly susceptible to being moved by waves within the shore-break (or across the surf zone with increased payload drag). This requires swimmer assistance for re-orientation and visual checks.
- c. Though only witnessed a few times, when there was positive buoyancy on the COM cable to reduce entanglement, the crawler can get stuck in the sandbed, thus requiring swimmer assistance.

## DETAILS

Operation Mode 1) land-based operator communicates via a bright-green underwater umbilical with the crawler controlling movements, while a swimmer assists in navigation and re-orientation

- a. Dead-reckoning does not perform well and requires swimmer assistance
- b. Swimmer re-orientates the crawler and communicates with shore-operator via hand signals
- c. Swimmers are limited by hazardous conditions, thus limiting the maximum operational depth and conditions
- d. Deeper operation will require SCUBA increasing personnel, which is not recommended
- e. Owing to the tethered umbilical operations are limited to 300m
- f. Umbilical cable has the tendency to get entangled with the crawler's tracks. Floatation was used to reduce entanglement. However, the floatation created positive lift ultimately causing the crawler to dig into the sediment and become stuck in the sandbed

Operation Mode 2) Retractable-tethered float – wireless communication to shore-base

- a. A retractable spool and small communication floatation were designed and constructed for the crawler to use surface GPS navigation
- b. Retractable spool mounted to the crawler reduces available payload space (70% surface platform was required, this aspect can be improved)
- c. Retractable-spool was designed using inexpensive off-the-shelf components increasing its size
- d. Retractable-spool worked well at various depths and under the influence of waves reducing the amount of positive lift and exposed cable, which could get entangled on future instrumentation
- e. System limited to 30m water depth, owing to the amount of available space for cable on the spool
- f. The spool acts as a moment arm causing the crawler to overturn when oriented 45degrees or greater to the incoming wave crest (orbital velocity). Small waves (<0.3m) are capable of overturning the crawler. This requires swimmer assistance.
- g. Owing to continuous over-turning the slip-ring connector failed, a new slip-ring connector is provided under warranty. The current slip-ring cost \$200 and a more robust slip-ring costs \$4800.

h. This operational mode has potential to work well with further development.

## **IMPACT/APPLICATION**

Understanding the morphodynamics of sedimentary environments is important for recreational, economic, and military reasons. This work will help to shed light on the importance of grain size on sediment transport and will help elucidate whether variations in grain size are important to or even drive changes in morphology in many coastal environments. In addition, the development of a suite of instruments on an amphibious crawler has the potential to revolutionize measurement in the coastal zone.

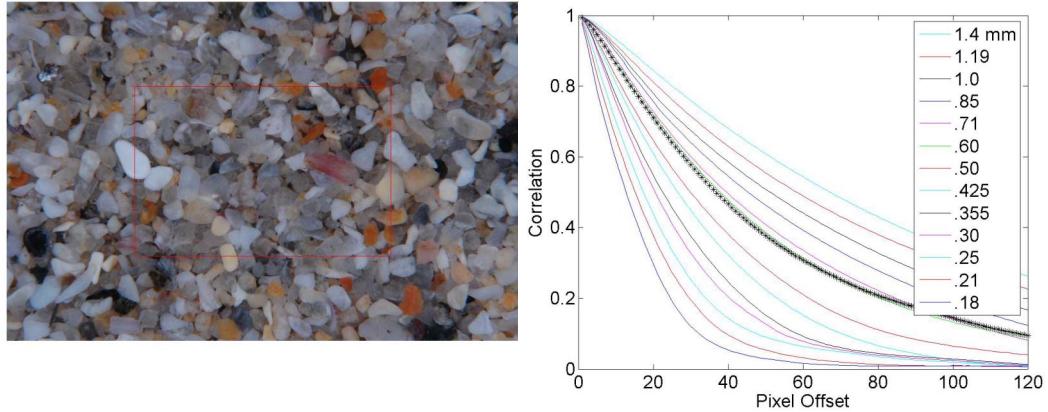
During the time that we have had the crawler in an operational mode, our developmental efforts have been successful. The crawler has potential to be used for limited near-bed measurements in hazardous areas, such as rip currents, or to obtain measurements that require periodic station-keeping, which can not be obtained by other AUVs. However, at this time, it requires the assistance of a human swimmer reducing the autonomous nature of the vehicle's intended use. The navigation requires improvement, which will improve most of the current operational problems.

The crawler's navigation is a disappointment. The system works the best in wavy environment when the crawler is controlled by an umbilical, but the navigation is virtually non-existent with dead-reckoning. The current system is functional, though limited, in its current status.

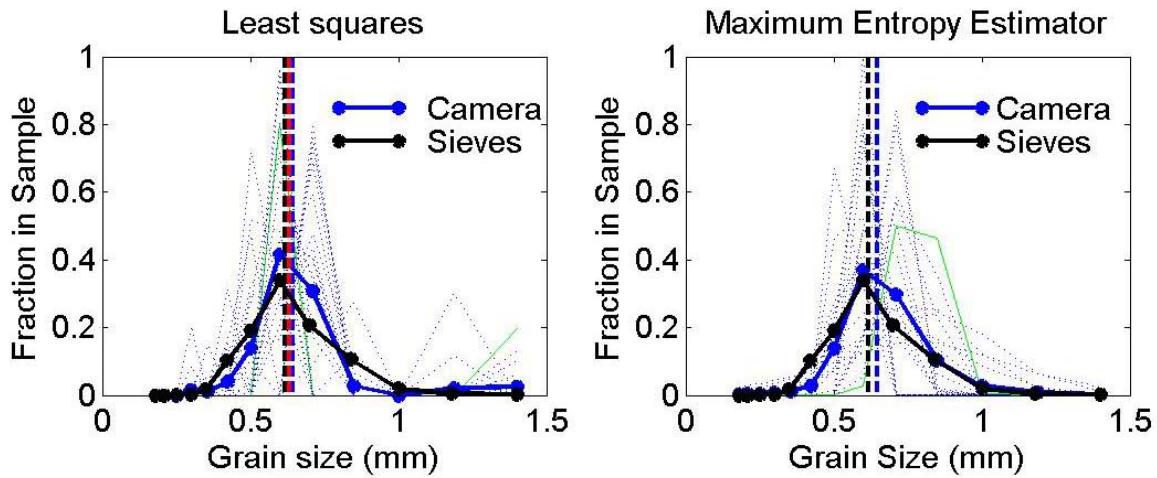
Suggestions for improvement

- 1) Use the system with its current limitations but with limited scope
- 2) If a tethered-float is required for GPS navigation, a smaller retractable cable spool should be constructed to reduce over-turning. In addition, a more robust slip-ring is required.
- 3) A new controller for autonomous navigation for dead-reckoning is strongly recommended.

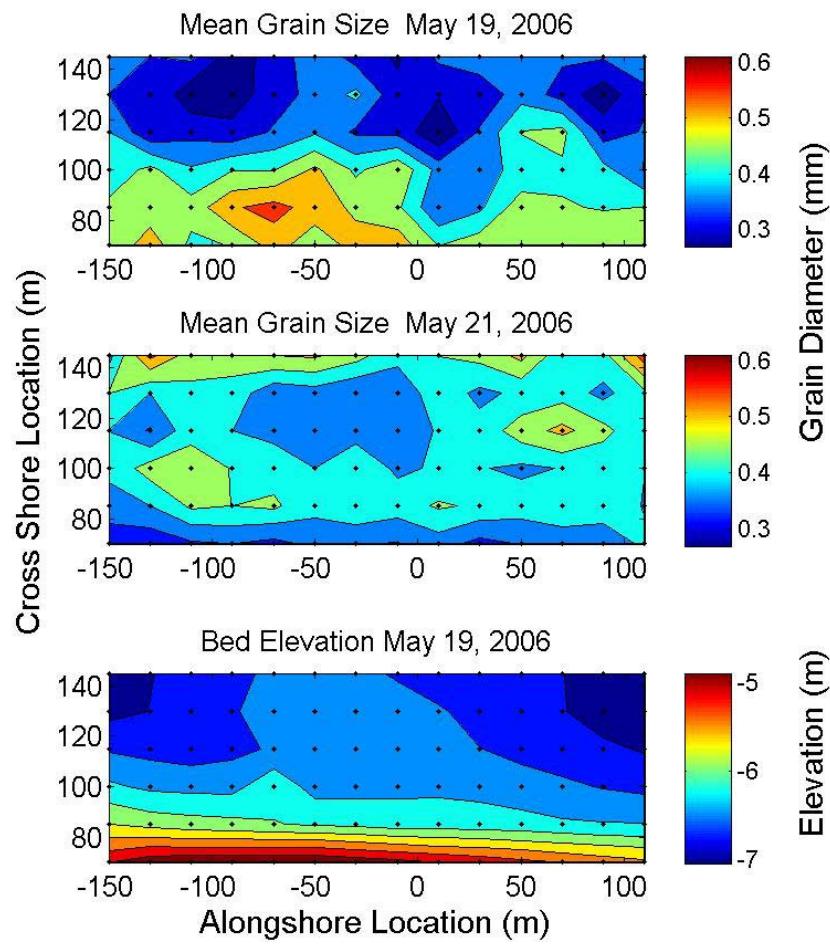
Figures 4, 5 and 6 show the crawler during testing at the beach in Monterey, CA.



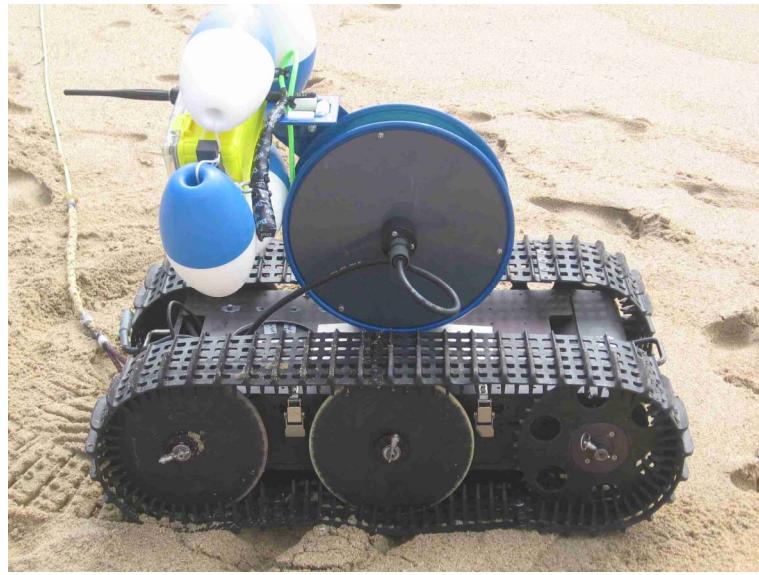
**Figure 1.** Example image of natural sand sample from Sennen, England (left panel). The red square represents the sub-image which is analyzed. Right panel: autocorrelation curve (asterisks) from image on left and calibration curves (thin lines) corresponding to different sieved fractions. [Correlation curves fall off from a value of 1 at 0 pixel offset to close to 0 for large pixel offsets. Curves for largest grains fall off slowly, curves for smallest grains fall off quickly. The natural curve, being a combination of all grains, falls off at an intermediate rate.]



**Figure 2.** Sand grain size distribution for one sample collected from the beach at Sennen Cove. The thin blue dotted lines represent grain size distributions from approximately 20 images taken of each sample (in the lab). In the left panel, distribution is calculated following Rubin (2004) using a least squares fit of the natural autocorrelation curve to the calibration curves. In the right panel, the distribution is calculated using the maximum entropy estimator. The thin green lines are the distributions calculated from the example natural image in Fig 2. The thick solid blue line in each panel represents the average of all the thin lines in that panel and therefore the average grain size distribution for that sand sample. The solid black line in each panel represents the grain size distribution measured using sieves. The vertical dashed lines represent mean grain size. The blue and the black vertical dashed lines are means calculated from the camera and sieved distributions, respectively, and the red vertical line is the mean calculated using Rubin's (2004) interpolation technique.



**Figure 3. Top)** Spatial map of mean grain size measured with the DIS on May 19, 2006, after many days of small ( $<1$  m) offshore wave heights. **Middle)** Spatial map of mean grain size measured with the DIS on May 21, 2006, after a storm with  $\sim 5$  m offshore wave heights. **Bottom)** Bathymetry measured before the storm of May 21, showing the smooth beach face slope and a 3-D, inter-tidal bar



**Figure 4.** A crawler on a sandy beach before surf zone operation. A retractable reel and float (underwater box with GPS and radio communication, and positive buoyancy required for floatation) mounted on the platform.



**Figure 5.** Crawler entering the surf zone during a lull in wave breaking.  
Person on the right for scale.



**Figure 6. Crawler on the entering the surf zone with only land-base tethered control**

## TRANSITIONS

This work has not yet lead to any transitions.

## RELATED PROJECTS

This work also is being supported by an ONR DURIP award to Dr. MacMahan.

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